Small Autonomous Underwater Vehicle (AUV) Wave Measurement System

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LONG-TERM GOAL

The primary goal is to develop, demonstrate, and implement techniques for cost-effectively obtaining non-directional and directional ocean surface wave spectra from small AUV's particularly those that are being developed under Office of Naval Research (ONR) sponsorship.

OBJECTIVES

This report describes a Phase II Small Business Innovation Research (SBIR) project to prove feasibility of estimating ocean surface wave spectra using small AUV's as measurement platforms. During the Phase I effort performed in FY99, the main objectives were to design and specify components of a suitable wave measurement system, to develop appropriate data analysis techniques that consider wave-induced AUV motion, and to demonstrate feasibility by realistic tests and simulations. During the Phase I option performed in FY00, the objective was to collect and analyze preliminary field data. During the Phase II effort now being performed, the main objectives are to design, build, and field test a complete prototype system. The system would also be used to collect wave data supporting military exercises and scientific investigations such as coastal processes studies.

APPROACH

During Phase I, use of miniature, low-cost, and low-power hull-mounted pressure sensors was planned and investigated in detail. Measurement of wave pressure, a scalar, involves less sensitive vehicle motion corrections than measurement of wave orbital velocity, a vector. The approach involves correcting pressure data for wave-induced vehicle motion using data from triaxial accelerometers and angular rate sensors that are either already incorporated into small AUV's or that can be added as part of a small wave measurement module. Proving system feasibility included MATLAB data simulations, AUV motion corrections, and development of new techniques to estimate wave spectra. The Florida Atlantic University (FAU) Ocean Explorer (OEX), a small AUV, was used in a temporary manner to collect preliminary field data off the Florida coast. Example processed directional wave spectra were provided in the FY00 annual report.

During initial Phase II work, John A. Bunce, Emery W. Hughes, Julio A. Melhado, and Ronald T. Miles developed specifications and wave measurement system integration requirements for purchase of a small AUV that will be used to extensively field test analysis techniques that are being developed. New

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14. ABSTRACT
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approaches developed by Leon E. Borgman (consultant) to obtain directional wave spectra from non-stationary sensors were further developed and tested using simulations. This work complements Marshall D. Earle's Phase I methods that treat the wave measurement system as a moving slope array.

WORK COMPLETED

The Phase I investigations showed that directional wave spectra can be cost-effectively obtained using hull-mounted pressure sensors or narrow beam upward-looking sonars with modified analysis. Other approaches, such as measuring wave orbital velocities near an AUV, were shown to involve more complicated instrumentation and more sensitive vehicle motion corrections. Mathematics was developed for processing both data types with corrections for wave-induced vehicle motion and Doppler shifts caused by vehicle horizontal translational motion. Because of low signal to noise ratios from across beam sensors, original measurement and data analysis techniques were developed to estimate directional wave spectra from sensors near a vehicle's bow and stern (a slope array). For small AUV's with bow and stern sensors, obtaining directional spectra involves operating a vehicle over easily navigated short paths. Determining non-directional wave spectra is easier due to simpler vehicle motion effects and the need for only one sensor. The methods were computer programmed and tested using MATLAB simulations. They were later field tested in a preliminary manner using data collected by a modified OEX small AUV and a pitch/roll/heave wave buoy. A new analysis technique was partly derived to obtain directional wave spectra from a non-stationary sensor space array (e.g. measurements made by an AUV at known time-varying positions). It would implicitly consider Doppler shift effects due to vehicle horizontal motion and could provide better wave direction resolution than the slope array approach.

The first task under the Phase II effort was selection of a suitable small AUV. Main deciding factors were vehicle size and weight, as well as cost to be within budget. Both launching and recovering the AUV from small boats would be desirable to facilitate several cost-effective field tests of the measurement and analysis techniques. Table 1 lists features of several small AUV's.

The Phase II budget for an AUV is limited. Phoenix is a research AUV being developed by the Naval Postgraduate School and is not commercially available. Odyssey and Ocean Explorer both cost more than $500K. Initial quoted prices for REMUS and FETCH were about $250K and $135K respectively making them the only vehicles in a roughly comparable and affordable price range.

Based on these initial investigations, final technical requirements were prepared and forwarded to the REMUS and FETCH teams. These requirements eliminated systems that were not required for the effort (e.g. CTD, forward looking sonar) and specified configuration changes for integration of the wave sensors and the electronic package to acquire and process wave data. The manufacturer of REMUS did not respond to the final bid request. The manufacturer of FETCH bid $134K which was accepted with government approval. These factors contributed to the decision to select FETCH as a test-bed AUV. A FETCH similar to the one being built is shown in Figure 1. The acquired vehicle will be somewhat different with sensor mounting points and internal changes to accommodate additional electronics.

Table 1. Features of Small AUV's.

Vehicle Name	Organization	Size (inches)*		Weight (lbs)	Speed (knots)	Range (hrs)	Depth (feet)	Sensors**
		Length	Dia.					
REMUS	Woods Hole Oceanographic Institution	55"	7.5"	68	3+	10	500	CTD, ADCP, depth, side-scan sonar, and navigation
ODYSSEY	MIT Sea Grant	82"	22"	360	3+	12	19000	CTD, ADCP, depth, side-scan sonar, GPS and navigation
OCEAN EXPLORER	Florida Atlantic University	84"	21"	900	3+	12	1000	CTD, ADCP, depth, side-scan sonar, GPS and navigation
PHOENIX	Naval Postgraduate School	72"	11"	450	3+	3	15	ADCP, depth, forward-looking sonar and navigation
FETCH	Sias Paterson Inc.	68"	16"	170	9	4	1000	CTD, depth, GPs, side-scan sonar, video and navigation

* Given here are minimum lengths. Sections can be added to expand capabilities.
** These are typical sensor packages. Additional sensors can be added to all vehicles.

Figure 1. Small AUV to be Used as Test-bed Vehicle.
[A small AUV, roughly 2 meters long, will be used to test the developed techniques.]

Two directional wave spectra estimation methods can be used with data measured by one or more moving small AUV's. One method was developed and field tested during Phase I. It treats the AUV as a moving slope array. The second method was identified during Phase I and is being developed during Phase II. It considers the data as being from a space array where horizontal positions of individual measurements are known varying functions of time. During initial Phase II research, the second method was further developed mathematically and was tested in preliminary ways using MATLAB simulations. The AUV is assumed to remain within an area of wave pseudo-stationarity. Procedures for moving sensor data are based on time domain statistical procedures utilizing stepwise, ridge regression with random selection of candidate transfer functions over a frequency and direction search block. The second method is also applicable to fixed position sensor arrays currently in use.

RESULTS

During FY99, measurement and data analysis techniques were developed and tested using simulations. During FY00, preliminary field data were collected and processed. Directional wave spectra from AUV measurements were compared to spectra obtained from simultaneous pitch/roll/heave buoy data. For the low height and short period waves during the tests, results were acceptable for vehicle operations shallower than 8 m depth where signal to noise limitations start to become important.

The Phase II effort began midway through FY01. A survey of AUV's was performed. Technical specifications for an AUV to be modified and acquired as a field test vehicle were developed. A modified FETCH vehicle was ordered and is under construction. The second of two analysis methods, a space

array analysis approach that applies to non-stationary sensors, was further developed and preliminarily tested with simulated data.

Overall research to date shows that non-directional and directional wave spectra can be determined effectively using a moving small AUV with simple pressure sensors. The data analysis procedures could be implemented in near-real-time for operational systems. An AUV wave measurement system has the potential, with further testing and validations, to be a usable operational payload for measuring ocean surface waves.

IMPACT/APPLICATIONS

Wave measurement capabilities under development would allow waves to be measured from the same small AUV's that ONR is already developing to support littoral military operations and scientific coastal investigations. A mobile AUV wave measurement system could map waves over much larger areas than could be covered with conventional fixed in-situ instrumentation. The significant spatial variability of coastal waves could be better investigated. Coastal processes models such as surf models could be initialized with system data.

TRANSITIONS

One future transition area is support of littoral military operations that may be adversely affected or limited by waves and resulting surf. Using wave measurement systems with almost any small AUV, including those sponsored by ONR, provides a system transition path to future procurements and operational use.

Another future transition area is using AUV wave measurement systems to support research including coastal processes and beach erosion studies, model initializations and validations, and remote sensing algorithm validations. Also, developed data analysis techniques could be applied to other types of wave measurement systems such as those on one or more surface ships or a group of drifting buoys with known Global Positioning System (GPS) positions.

RELATED PROJECTS

Techniques employed to correct hull-fixed measurements for vehicle motion utilize data already measured by several small AUV's. Or, when other AUV's are used, data may be acquired and processed by a sensor/electronics module similar to that in wave measurement buoys developed by Neptune Sciences under Space and Naval Warfare Systems Command (SPAWAR) sponsorship. The space array data analysis method is being examined for use with GPS tracked wave buoys that are being sold commercially by Neptune Sciences after development as an outgrowth of an earlier ONR Phase I and II SBIR project, Family of Miniature Expendable Expendable Sensors.

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PUBLICATIONS

Borgman, L.E., and Earle, M.D., Estimation of Directional Wave Spectra from Non-Stationary Wave Sensors, <u>Ocean Wave Measurement and Analysis</u>, Proceedings of the Fourth International Symposium Waves 2001, ASCE, submitted, publication during 2002.